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# DETERMINATION OF THE HEAT-ENGINEERING PARAMETERS OF A GLASS-MELTING TANK FURNACE IN CHANGING FROM OIL FUEL TO NATURAL GAS

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The distribution of the thermal load between the burners of the glass-melting tank furnace is optimized and the conditions providing for the melting of the batch not further than opposite the second pair of burners are identified. Operating conditions that ensure complete combustion of fuel with an optimum quantity of excess air are determined. Recommendations are issued for the rational implementation of natural gas combustion in this type of furnace.

The intensity of the technological processes in glass-melting furnaces to a large extent is determined by their heat work. Due to the endothermic type of the glass-melting reactions, generation of heat inside the melting tank is virtually excluded, unless the glass melt is additionally heated by electricity directly in the tank. Consequently, the temperature level of the process depends only on the amount of heat absorbed by the melt surface as a consequence of heat exchange with the high-temperature gases and the refractory brickwork of the flame space. Therefore, intensification of the external heat exchange in glass-melting furnaces is one of the most effective methods for increasing the furnace efficiency and decreasing the fuel rate.

Numerous studies [1 – 3] indicated that the main method of intensifying the glass-melting processes is providing for a high melting temperature. An increase in the process temperature has a positive effect on the rate of the physicochemical transformations in glass melting. The authors of [4] noted a sufficiently clear relationship between the thermal load of the furnace and its output, which, in turn, largely depends on the temperature level of the process. On the one hand, a transition to a higher melting temperature under a constant output level requires a substantial increase in the thermal load, and on the other hand, an increase in the furnace efficiency resulting from an increased melting temperature makes it possible to reduce the specific consumption of thermal power.

Efficient external heat exchange in the workspace of a glass-melting furnace depends not only on the thermal load in the respective zones of the furnace (melting, clarification, and chilling), but also on a rational fuel combustion method. It is known that the heat transfer from the flame to the glass melt surface depends on its aerodynamics, i.e., on the necessary stiffness and flatness with respect to the glass melt surface and on the radiation parameters ensuring a maximum radiating capacity for a particular type of fuel (fuel oil or natural gas) due to an increased extent of blackness (luminosity) and temperature [5].

The results of theoretical calculations of the heat-exchanges processes [6] and the practical experience of existing furnaces confirm that glass-melting open-flame furnaces of various designs have typical optimum flame lengths that ensure maximum heat transfer to the glass melt due to the above-mentioned factors.

The composition and pressure of the fuel combustion products filling the workspace of the furnace may influence as well the quality of the glass melt produced, since the mass-exchange processes are determined by the partial pressures of the respective gas components in the melt and the surrounding gas medium. Therefore, a modification of the composition and pressure of the gases in the flame space may impair the quality of glass and, accordingly, decrease the furnace efficiency.

The Ufimkinskii Glass Factory (Sverdlovsk Region) that produces container glass for various purposes encountered the problem of identifying the rational thermal conditions for a glass-melting furnace that was converted from fuel oil to natural gas heating. It is known that the glass melt intended for glass containers should be well melted and clarified. Cords, unmelted spots, open and non-puncturable bubbles inside the product or on its surface, and any contaminants not removable by cleaning liquid are inadmissible. In addition to the physiochemical properties prescribed by the regulatory documents, the bottles should have high mechanical strength: they should withstand pressure of 0.8 MPa.

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**TABLE 1**

| Number of the pair of burners | Composition of waste gases, % | | | Air flow coefficient | Chemical under-burning, % |
|---|---|---|---|---|---|
| | $CO_2$ | $O_2$ | CO | | |
| *Initial operating conditions* | | | | | |
| 1 | 10.4 | 0.6 | 3.4 | 0.954 | 1.23 |
| 1 | 11.4 | 0.4 | 2.4 | 0.966 | 0.871 |
| 2 | 10.0 | 0.0 | 2.6 | 0.952 | 0.944 |
| 3 | 10.6 | 0.0 | 2.8 | 0.943 | 1.016 |
| 1 | 11.0 | 0.2 | 3.2 | 0.942 | 1.161 |
| 2 | 8.4 | 0.2 | 4.0 | 0.928 | 1.452 |
| 3 | 9.6 | 0.2 | 2.4 | 0.959 | 0.871 |
| *Conditions with an increased air flow rate* | | | | | |
| 1 | 13.2 | 2.2 | 0.2 | 1.104 | 0.073 |
| 2 | 10.8 | 0.6 | 0.4 | 1.017 | 0.145 |
| 3 | 10.4 | 1.4 | 0.0 | 1.064 | 0.0 |
| 1 | 10.9 | 1.0 | 0.0 | 1.042 | 0.0 |
| 2 | 10.8 | 1.4 | 0.0 | 1.064 | 0.0 |
| 3 | 10.6 | 1.6 | 0.0 | 1.074 | 0.0 |

**TABLE 2**

| Number of the pair of burners | Composition of waste gases, % | | | Air flow coefficient | Chemical under-burning, % |
|---|---|---|---|---|---|
| | $CO_2$ | $O_2$ | CO | | |
| *The first pair of burners under a modified supply of compressor air* | | | | | |
| 1 | 14.4 | 1.4 | 0.0 | 1.304 | 0.0 |
| 2 | 13.2 | 1.6 | 0.0 | 1.076 | 0.0 |
| 3 | 13.8 | 1.2 | 0.4 | 1.047 | 0.145 |
| 1 | 14.0 | 1.8 | 0.0 | 1.087 | 0.0 |
| 2 | 14.2 | 1.2 | 0.0 | 1.056 | 0.0 |
| 3 | 14.0 | 1.2 | 0.0 | 1.056 | 0.0 |
| *Supply of fan air with fully opened valve* | | | | | |
| 1 | 11.0 | 3.8 | 0.0 | 1.202 | 0.0 |
| 2 | 9.6 | 4.0 | 0.0 | 1.211 | 0.0 |
| 3 | 9.0 | 5.0 | 0.0 | 1.280 | 0.0 |
| *Supply of fan air with valve50% closed* | | | | | |
| 1 | 13.6 | 1.2 | 0.0 | 1.056 | 0.0 |
| 2 | 11.2 | 1.6 | 0.0 | 1.074 | 0.0 |
| 3 | 9.2 | 4.4 | 0.0 | 1.238 | 0.0 |

Our study was performed in a regenerative tank glass-melting furnace with a melting tank surface area equal to 60 m$^2$. The furnace is intended for melting dark brown glass for beer bottles. The furnace is equipped with three pairs of shaft burners forming a system of three flames with a lateral flame direction. The furnace is heated by natural gas, and the air for combustion is supplied due to rarefaction developed by a smoke stack 70 m high.

It was primarily necessary to ensure the necessary stiffness, flatness, and luminosity of the gas flames. Previously the fuel oil flames used to satisfy all imposed requirements, but after natural gas heating was introduced, the flames formed in the flame space were limp even under maximum thermal load, did not cover the melt surface, bent towards the roof, and were virtually uncontrollable. Naturally, it was impossible to maintain an optimum flame length. It was recommended to use gas-air lances and a burner ensuring the optimum angle of the flame with respect to the melt surface [7], which were designed at the Ural State Technical University.

Next, a full investigation of the thermal work of the furnace was carried out. The first step was the evaluation of the quality of fuel combustion in each pair of burners using the previously established gas distribution between the burners, which was monitored on the basis of the pressure in front of the burners (8.8 and 5.0 kPa, respectively). The gas analyzes revealed substantial underburning in all smoke-deflecting burners. The CO content in the furnace gases varied within the limits of 2.4 – 4.0%, which corresponded to an air flow coefficient of 0.928 – 0.966. We selected an air regime ensuring complete combustion of fuel with a minimum quantity of excess air.

The results of the analysis and the calculation of the air flow coefficient and the value of chemical underburning are listed in Table 1.

It was observed that the flame at the exit from the burner leapt upwards instead of covering the melting batch. At the same time, the length of the flame was excessive, since its tongues reached beyond the flame space width. By a modification of the compressed air supply (the pressure was raised from 170 to 190 kPa), the necessary length and stiffness of the flame were ensured. The purpose was to maintain a constant oxygen content in the waste gases equal to 1.2 – 1.6%, same as in the preceding experimental series. As a result, it became possible to preserve the range of the air flow coefficient variation within the required limits (Table 2).

It should be noted that all the controlled furnace parameters (the temperatures of the melting zone, the working zone, and the roof) remained virtually constant, and the temperature near the stack base decreased slightly (from 480 to 440°C).

The recommended air-conducting burner head with the optimum arch and lining angles ensures the required effect in using fan air. It was decided to test the furnace performance with a forced air feed using a fan (Table 2). When the fan air was fed into the furnace, the flames became flatter and visibly receded from the burner nozzle. The side and upper tongues of the flames disappeared and the flames acquired clear contours and shapes.

A similar gas distribution was registered at the opposite side of the furnace (9, 7 and 5 kPa). All monitored parameters remained at the required technological level and the non-melted batch opposite the second pair of burners disappeared. A clearly visible smooth surface of the glass melt was observed.

It was earlier established [5] that the flame length in all pairs of burners should not exceed 2/3 of the width of the flame space, which can be provided only by supplying compressor air.

We optimized the thermal load distribution between the pairs of burners and developed a regime ensuring the melting of the batch not further than near the second pair of burners. The gas supply to the first pair of burners was finally in-

creased to 10 kPa, the supply to the second pair was 8 kPa, and the feed to the third pair was decreased to 4 kPa. The furnace parameters were continuously monitored for several hours and their variations were promptly corrected.

The appearance of an unmelted batch opposite the second pair of burners points to the insufficient thermal load of the first pair. In the case of three glass-forming machines operating, the thermal load on the first pair of burners should be increased to 10 kPa with an obligatory use of compressor air, whose flow rate is visually determined based on the flame length and flatness (2/3 of the width of the flame space). The gas flow rate in the second pair of burners can be preserved at the previous level (8 kPa), but the quantity of compressor air supplied to it should be significantly lower (its flow rate can be controlled by the valves on the individual pipelines connected to the nozzles, which, however, do not have individual manometers).

The gas flow rate in the third pair of burners should be left at the minimum level (about 4 kPa). An attempt to fully exclude the feed of compressor air to the nozzles of the third pair was unsuccessful: the flame became too long and limp and leapt upwards. Therefore, the feed of compressor air to the last pair of burners is needed only for flame shaping.

Thus, to achieve adequate operation of the furnace, it is necessary to ensure complete combustion of fuel and a correct distribution of thermal load between the pairs of burners.

A maximum thermal load should be applied to the first pair of burners (with a compulsory enforcement of the complete fuel combustion). The load on the second pair of burners should be adjusted based on the temperature of the flame space registered by measuring instruments (for the furnace considered it was 1520°C). In the case of overheating, it is recommended to decrease the load applied to the second pair of burners without disturbing the first pair.

The gas flow rate in the third pair of burners should be adjusted based on the working tank temperature (1380 – 1400°C). The missing quantity of air for combustion in the first pair of burners can be compensated by increasing the supply of compressor air via the gas nozzles. To supply air for gas combustion, a fan should be used, which makes it possible to achieve an optimum angle of the flame with respect to the melt surface.

## REFERENCES

1. K. T. Bondarev and V. V. Pollyak, “High-temperature melting of glass,” *Steklo Keram.*, No. 1, 8 – 12 (1971).
2. O. K. Botvinkin and T. B. Zhuze, “A study of the glass-formation process within a temperature range of 1400 – 1700°C,” *Steklo Keram.*, No. 1, 12 – 13 (1971).
3. Yu. A. Knyazev, A. I. Matveev, A. A. Nasypaiko, et al., “Start-up and operation of a tank furnace in high-temperature conditions,” *Steklo Keram.*, No. 1, 17 – 19 (1971).
4. V. G. Lisienko, V. B. Kut’in, S. N. Gushchin, and Yu. V. Kryuchenkov, “Reserves for the intensification of the thermal performance of a regenerative tank furnace for melting container glass,” *Steklo Keram.*, No. 8, 13 – 16 (1998).
5. S. N. Gushchin, V. G. Lisienko, and V. B. Kut’in, *Modeling and Control of the Thermal Work of Glass-Melting Furnaces* [in Russian], Ekaterinburg (1997).
6. V. B. Kut’in, S. N. Gushchin, and V. G. Lisienko, “Heat-exchange processes in a glass-melting furnace with a lateral flame direction,” *Steklo Keram.*, No. 6, 7 – 9 (1997).
7. V. Ya. Dzyuzer, N. I. Kokarev, V. B. Kut’in, et al., “Intensification of the thermal performance of glass-melting tank furnaces,” *Steklo Keram.*, No. 10, 16 – 17 (1997).
8. V. Ya. Dzyuzer, S. I. Pechenkin, N. I. Kokarev, et al., “Dependence of flame aerodynamics on the design parameters of the shaft burner,” *Steklo Keram.*, No. 12, 13 – 14 (1974).